

THE MECHANICAL CHARACTERIZATION OF E GLASS (WOVEN FABRIC) FIBER REINFORCED COMPOSITE MATERIAL

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ABSTRACT

Glass fiber reinforced polymer composites are the most common of all reinforcing fibers for polymeric matrix composite for several applications. This paper describes the fabrication of E-glass woven fabric mat fiber composites with different types of woven mat and different types of orientation and investigations of the same. Mechanical characterization of the composites were done by testing the composite lamina for tensile, compressive, flexural and impact strength. The composites manufactured by hand lay-up process with the volume fraction of fiber up to 0.60. It was found that the E-glass 400 woven composites proved better properties than the 600 woven composite alone in flexural strength. However, the E-glass 600 woven composites is superior to 400 woven composites in its tensile, compressive and impact strength. The fracture surface structure of the composite was observed under a Scanning Electron Microscope (SEM) and the cracks, holes and fiber delamination have also been analysed.

KEY WORDS: E-Glass, Resin, Composite, SEM & Woven Fabric

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1. INTRODUCTION

Glass fibers are the most common of all reinforcing fibers for Polymeric Matrix Composites (PMC). The primary advantages of glass fibers are low cost, high tensile strength, chemical resistance and insulating properties. E-glass has the lowest cost of all commercially available reinforcing fibers, which is the reason for its widespread use in the Fiber Reinforced Polymer (FRP) industry. Many authors have previously investigated the features of glass composite, Tasdemirci et al [1] determined the quasi-static and high strain rate compression behaviours of an E-glass/polyester composite in longitudinal, transverse, and through-thickness directions. Giovanni Belingardi et al [2] studied the mechanical tests and micro structural investigations. The impact test results of nano composite materials were improved with the addition of nanoclay in epoxy matrix. Singh et al[3] studied the preparation and mechanical properties of nanoclay composites with different weight ratio and suggested that water resistance property was improved by the addition of glass fiber and nanoclay. Lingesh et al[4] studied the mechanical behaviours of the short glass fiber of polyamide66 and polypropylene composites. Pradeep et al [5] investigated the enhancement of mechanical properties of glass fiber composite, when increasing blast furnace slag percentage improves mechanical properties. Irina et al [6] studied the mechanical performance for hybrid composites of glass fiber and plain woven carbon fiber. Thomas Bru et al [7]

investigated the mechanical properties of uni-weave carbon fibre. Satnam Singh et al [8] investigated the mechanical behaviour of glass fiber reinforced epoxy composites when increasing 20 % of the weight fraction of glass fibers over pure epoxy, the tensile strength and flexural strength increased. Jaganatha et al [9] studied tensile properties and also measured breaking load. The inclusion of carbon fiber mat reinforced polymeric composite significantly enhanced the ultimate tensile strength, yield strength and peak load of the composite. Patil Deogonda et al [10] examined the bending load, bearing strength of composite fiber by increasing the addition of filler. Vijaya Ramnath et al [11] used natural fibers and woven roving at low cost polymer composite developed with realistic mechanical properties. Ravi Ranjan et al [12] investigated the banana and sisal fiber improving mechanical properties. Heo et al [13] studied manufacturing bipolar plates using moulding technique improves mechanical properties. Donnell et al [14] vacuum-assisted resin transfer molding used to manufacture bio-based composite with high strength for automobile industry. Oksman et al [15] studied the natural fibers as reinforced polymer to improve mechanical properties for polylactic acid/flax composites. Akermo et al [16] modelling and experimental work performed using compression moulding. Singleton et al [17] studied the mechanical properties and also evaluated the tensile and impact loading for composite material using natural fiber. Elanchezhan et al [18] investigated the mechanical properties and behaviour of kenaf based hybrid composite. Shubhan et al [19] studied the mechanical properties of epoxy laminated composites with and without carbon nanotubes. Narendra Kumar Attili et al [20] analysed the mechanical properties of chopped strand mat of e-glass(450gsm) of five different types of composite to fabricate 0%wt, 5%wt, 10%wt, 15%wt and 20%wt of silica powder. Pavithran et al [21] improved the properties of coir-polyester composites by using glass as the intermediate layer between the coir layers. In the present work, an attempt has been made to fabricate E-glass(200,400,600) fiber woven mat composite and analyse the mechanical properties.

2. MATERIALS AND EXPERIMENTAL TECHNIQUES

2.1 E-Glass Fibers

Raif sakin et al [22] investigated the glass fiber woven (800g/m², 500g/m², 300g/m² & 200g/m²) and glass fiber mat (225g/m², 450g/m² & 600g/m²) for fatigue behaviours. Glass fiber woven(800g/m²) has the highest fatigue and fiber mat over the others. In the present investigation we have chosen E-glass fiber(200g/m², 400g/m² & 600g/m²) woven fiber composites because of which are made from extremely fine fibers, lightweight and strong.

2.2 Epoxy Resin and Hardener

Epoxy resin (LY556) possesses good binding properties between the fiber layers to form the matrix. The epoxy resin is used at room temperature. Hardener (HY951) is employed to improve the interfacial adhesion and impart strength to the composite. A resin and hardener mixture taken in the ratio 10:1 is used to obtain optimum matrix composition as it provides the suitable interfacial bonding between the fibers.

2.3 Fabrication Procedure for Composite Laminate

The composite materials were fabricated using compression moulding technique. They have stacked layer by layer of about 10 layers to attain the thickness as per the American Standard for Testing of Materials (ASTM) Specimen. Bonding agent (epoxy resin) was applied to create bonding between fiber sheets. Compression molding is a well-known technique to develop a variety of composite products. It is a closed moulding process with high pressure application. Two matched metal moulds are used to fabricate composite product. In compression moulder, base plate is stationary while upper plate is movable. Reinforcement and matrix are placed in the metallic mold and the whole assembly is kept

between the compression moulder. Heat and pressure is applied as per the requirement of composite for a definite period of time. The material placed between the moulding plates flows due to the application of pressure and heat and acquires the shape of the mould cavity with high dimensional accuracy which depends upon mould design. Curing of the composite may be carried out either at room temperature or at some elevated temperature. Here ten piles of E-glass woven fabric fiber are taken by one over the other and epoxy resin has been used as an adhesive. The size of the mould taken is (250x110x30) mm. The list of ingredients of composite laminate is shown in the Table 1. Initially the glass fiber is to be cut in the required shape of the size 250 mm \times 110 mm of required orientation (Figure 2). A thin plastic sheet is also used at the top and bottom of the mould in order to get good surface finish for the laminate. The mould has to be cleaned well. After that Poly Vinyl Acetate (PVA) is applied in order to avoid sticking of the laminate to the mould after curing of the laminate.

Sufficient amount of resin which is prepared beforehand by using 40% hardner(HY951) of the resin is to be mixed with the resin and stirred well. This mixture is poured over the ply. The resin is poured in to the mould uniformly and it is rolled in order to get the required bonding by using a rolling device. Enough care should be taken to avoid the air bubbles formed while rolling. The compression is applied on the fiber- resin mixture by tightening the two mould plates uniformly.

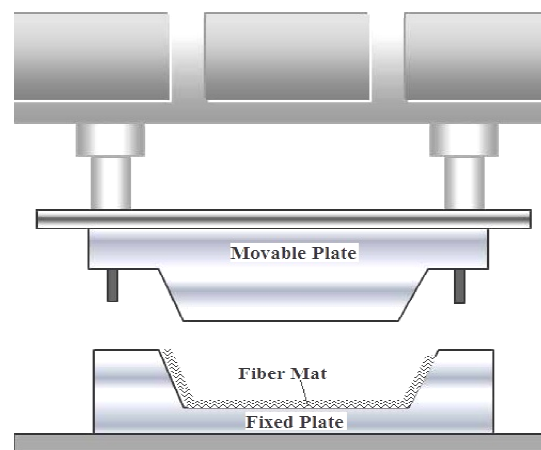


Figure 1: Compression Moulding

Table 1: List of Ingredients to Prepare a Composite Laminate

Type of Resin	Epoxy
Type of fiber	E-Glass(200,400,600 Woven Fabirc)
Hardner used	HY 951
No. of Plies per laminate	10
Nature of Laminate	Symmetric Type
Method of Preparation	Compression Moulding Method

Utmostcare should be taken to provide uniform pressure on the laminate while fixing the plates. After enough curing time (24 hrs), the laminate is removed from the mould plates carefully.



Figure 2: Diagram of E-Glass Woven Fabric Mat Fiber

3. TESTING OF COMPOSITES

3.1 Analysis of the Mechanical Properties

The tensile, flexural, compressive and impact strength of the specimens were analysed as per ASTM standard for testing of materials (ASTM:D638), (ASTM:D790), (ASTM:D695) and (ASTM:D256), using computerized Universal Testing Machine (UTM) at a cross-head speed of 50 mm/min. Figures 3, 4 and 5 indicate the ASTM specimens of composite testing.

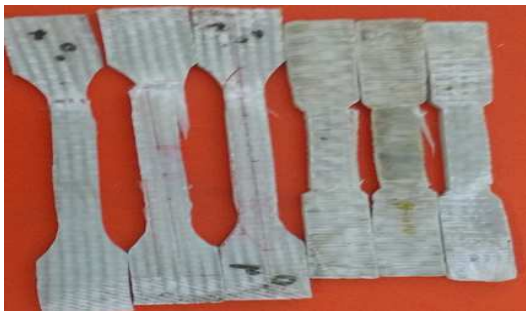


Figure 3: Tensile Test Specimens



Figure 4: Flexural Test Specimens



Figure 5: Impact Test Specimens

4. RESULTS AND DISCUSSIONS

4.1 Tensile Properties

The three different composite specimens like E-glass–200–400–600 woven mat were tested in the universal testing machine to find the tensile properties. A sample graph showing stress and strain of 200–400–600 woven mat is shown in Figure 6. The mechanical properties of the fabricated composite (E-glass–200–400–600 woven fabric mat) are summarized in the Table 2. It is seen that the tensile strength of the 400 and 600 mat is high, when compared to the 200 woven fabric mat. The tensile modulus are calculated from the linear portion of the graph. All the composites are manufactured at the highest volume fraction of 0.60.

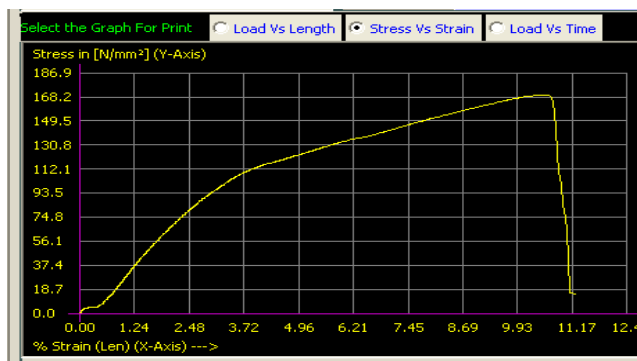


Figure 6: Stress- Strain Curve for Woven Fabric Mat

Table 2: Results of Tensile Test of Different Composite

Sample	Break Load (kN)	Maximum Displacement (mm)	Elongation (%)	Tensile Strength (MPa)	Tensile Modulus (MPa)
200 Woven Fabric	16.45	3.6	11.34	46.81	47
400 Woven Fabric	24.82	5.32	14.37	95.15	87
600 Woven Fabric	23.13	4.78	13.98	231.73	225

The comparison between different composites for break load, maximum displacement and percentage of elongation are shown in Figure 7. It is found that the break load of the 400 mat is high. The maximum displacement is also high for the 400 mat. Even though the displacement is higher the tensile strength and modulus of the composite is less than that of 200 and 400 mat which means that the 600 woven mats withstands more strain than the 200 and 400 mat before failure. Thus, it can be concluded that the E-glass woven fabric composite is more ductile than the glass fibre composite. From the results of the tensile test, it can be concluded that the 600 woven fabric mat composite is well performed when compared with other types of mat. This has also been experimentally proved by increasing strain rate [23].

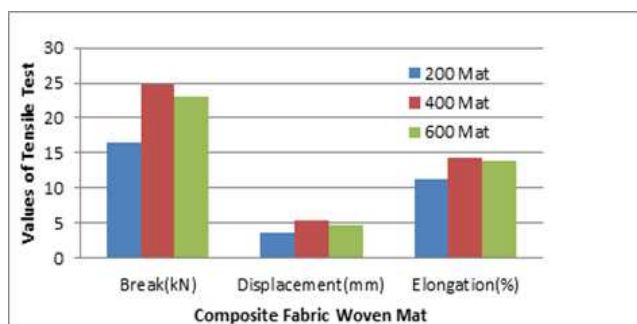


Figure 7: Comparison between Different Composite: Break Load, Displacement and % of Elongation

4.2 Flexural Properties

A typical load–displacement curve for composite is shown in the Figure 8. It is seen that the curves increase linearly with respect to displacement up to the maximum flexural load of 1.48 (kN) and then decreases since breakage takes place. The maximum flexural strength is observed in 400 mat fibre. The flexural resistance of other composites is

shown in the Table 3. With 400 woven the fabric mat has the highest flexural resistance due to the presence of uniformly distributed E-glass woven fabric fiber and its high stiffness. Moreover, the adhesion between the fibre and the epoxy matrix is better than the other two composites. The results are in alignment with the findings of Satnam Singh et al [9] where the increasing volume fraction of composites proves improved mechanical properties.

Table 3: Results of Flexural Test of Different Composite

Sample	Flexural Break Load (kN)	Maximum Displacement (mm)	Flexural Strength (MPa)	Flexural Modulus (MPa)
200 Woven Fabric	1.03	3.74	12.70	247
400 Woven Fabric	1.48	4.76	44.90	278
600 Woven Fabric	1.28	4.12	34.80	217

The flexural modulus of the composite is shows 400 mat has the highest flexural modulus when compared with the other two composites. The comparison between different composites break load and displacement are shown in Figure 9. The maximum displacement is marginally higher for the 400 mat, when compared to the other two types of mat. After the maximum flexural load point, the graph decreases and shows random behaviour since the fibres tend to pullout from the composite at the breaking point.

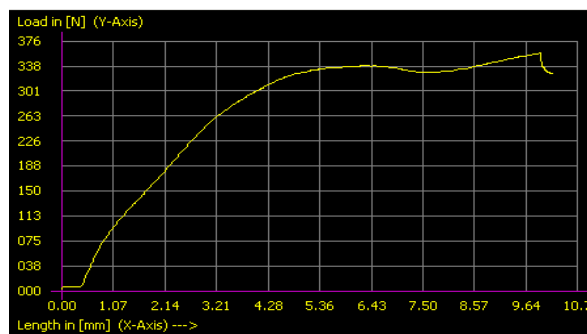


Figure 8: Load Vs Displacement (Fabric Woven Mat) for Flexural Test

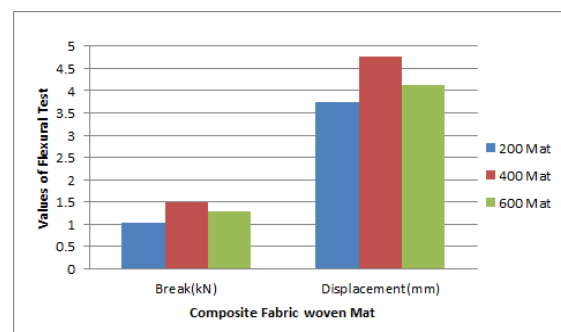


Figure 9: Comparison between Different Composite: Break Load, Displacement

4.3 Compression Properties

A typical load–displacement curve for three different types of composites, is shown in the Figure 10.

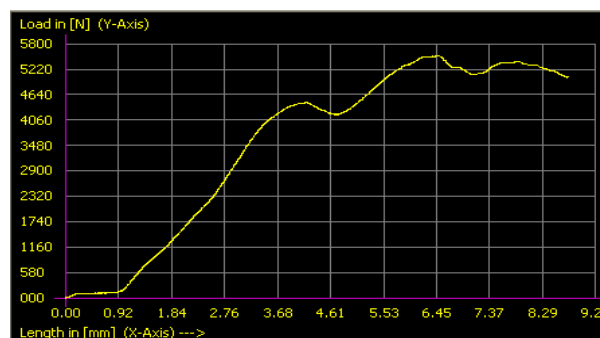


Figure 10: Load Vs Displacement (Fabric Woven Mat) for Compressive Test

The compression test results are summarized in the Table 4. The comparison between different composites break load and displacement are shown in Figure 11. It can be seen that as the load increases, the displacement increases linearly presenting elastic nature. Then there is a gradual decrease in the graph as the displacement increases. It can be seen that the curve follows almost smooth and are regular linear pattern. The yield load is calculated from curve.

Table 4: Results of Compressive Test of Different Composite

Sample	Break Load (kN)	Maximum Displacement (mm)	Compressive Strength (MPa)
200 Woven Fabric	1.5	2.37	11.3
400 Woven Fabric	2.49	3.05	17.63
600 Woven Fabric	2.03	2.89	76.14

The maximum break load is obtained for the 400 mat composite which is equal to 2.49 kN. The maximum displacement is also high for the 400 mat, but the maximum compressive strength is found in the 600 woven fabric mat.

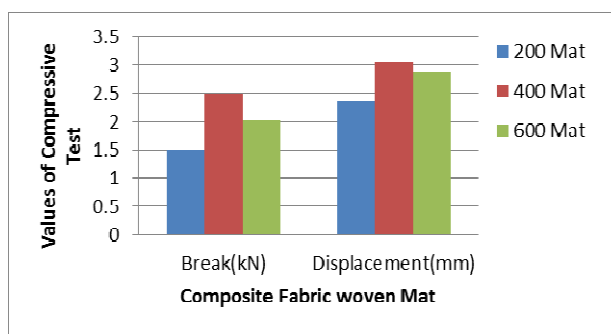


Figure 11: Comparison between Different Composite: Break Load, Displacement

4.4 Impact Properties

The impact test is conducted for analysing the impact capability of three different composites. The loss in energy has been found by using charpy impact test machine(100 tonne capacity).

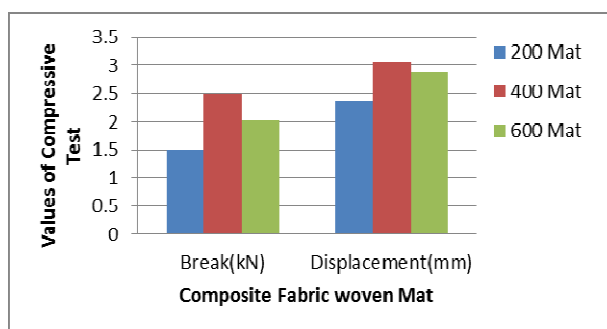


Figure 12: Comparison between Different Composite: Break Load, Displacement

The energy absorbed by the each specimen is summarized in the Table 5. The comparison of the impact test results of different composites is shown in Figure 12. It can be seen that the 600 mat have very high impact strength when compared to other mat composites. The energy absorbed by the 600 mat fibre is 18.21 J. The reason for such high strength is due to the presence of single type fibre in the matrix in alternating directions. Thus, when the crack propagates it travels

through the matrix and the fibres of the composite. Impact results are in alignment with the findings of Mallick and Cartie[24&25] have found that stacking arrangement of the fibers is more important than composition in defining impact toughness and resin toughness relatively than fiber strength and stiffness is the main parameter influencing the impact resistant properties of the composites.

Table 5: Results of Impact Test for Different Composite

Sample	Energy Absorbed (Joules)
200 Woven Fabric	4.51
400 Woven Fabric	7.08
600 Woven Fabric	18.21

5. MORPHOLOGICAL ANALYSIS

Morphological analysis was done using Scanning Electron Microscope (SEM). The samples were taken from each test, dried and coated with 15–20 nm thick layer of gold with an ion-sputter coater device. Subsequently, the specimens have inspected by a scanning electron microscope. The interfacial adhesion between the matrix and the fibre is clearly seen from scanning electron micrographs. The scanning electronmicrograph of the 200-400-600 fabric woven mat is shown in Figure 14. Even though the manufacturing of the composite has been done with care, it is seen that there is an intra fibre delamination primarily present in the woven fabric which reduces the strength of the composite. Figure 13 shows the adhesion of fibre and resin in 0.6 volume fraction of E-glass woven fabric mat composite which is subjected to tensile testing.

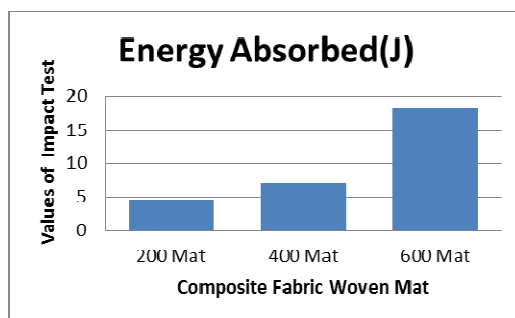


Figure 13: Comparison of Impact Test Result of Different Composite

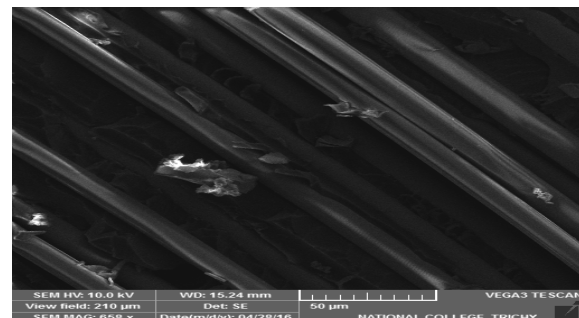


Figure 14: SEM Image of E-Glass Fiber

In general, the adhesion is good, although there are a few defects like air bubbles and pull out. The smooth surface is the resin and the irregular surface is the fibre. Due to the high strength of E-glass composite, they have undergone individual breakage, giving it very high strength. The effective stress transfer in the tensile direction between the fibers and matrix is supported by the high stress values obtained in the test. Figure 16 shows the SEM micrograph of flexural fractured specimen. Inter-phase delamination is found at the cross-section of applied load. Presence of voids in the specimen is found to be minimal due to uniform load applied on it.

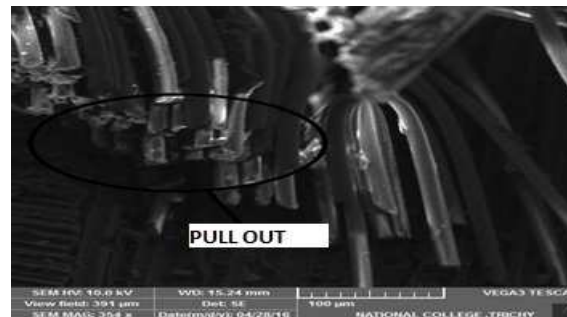


Figure 15: Pull Out of Fiber

The crack propagates through the glass fibers rather than the other fiber and causes failure. Flexural strength values also indicate that there is very little stress transfer from the matrix to the fiber and hence very low values.

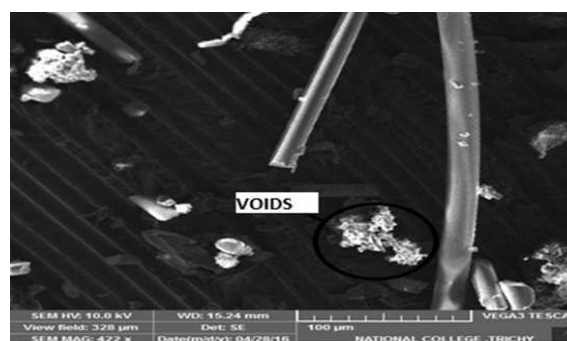


Figure 16: Voids of Fiber

6. CONCLUSIONS

In this research work, different E-Glass woven fabric composites are fabricated with fibres mat 200, 400 and 600. All the composites have the highest volume fraction of 0.60. Their mechanical properties like tensile strength, compressive, flexural strength and impact strength have been investigated and from the results obtained, the following conclusions are drawn.

- The tensile strength of 600 mat is the highest among all the composites which has the value of 23.13 kN.
- The percentage of elongation of 200 fabrics, woven mat in tensile testing is found to be less than that of the other types of mat composite. Therefore, the 600 woven mat withstands more strain before failure in tensile testing than the 200 and 400 woven fabric mat fibre composite.
- The flexural strength of the composite is in decreasing order from 400 mat, 600 mat and 200 mat. 400 mat has the highest flexural strength as its strength increases with increase in interfacial adhesion. Flexural modulus is also found to be highest for the 400 fabric woven mat.
- Compressive test results show that 600 mat is highest among all the three manufactured composites.
- Impact strength of 600 woven mat composite is 18.21 J which is quite high when compared with the 400 mats and 200 mat whose impact values are 7.08 J and 4.51 J respectively.

The effect of the different tests is studied and the microstructures of composites have been investigated using SEM and it is found that the orientation angles of fibres play an important role in the mechanical behaviour of natural fibre

composite. SEM micrographs of the tensile, flexural, impact and impact tested specimens help to predict fibre failure, presence of voids and fibre pullout during loading condition. It also gives an idea about the crack propagation in the composite. From the above results, the E-glass woven fabric composite is found to be the best option for general applications. E - glass composites can be used for applications which call for high impact strength. Moreover, they have higher mechanical properties as discussed above and hence can be used for a variety of applications which includes housing, automobile and packaging industry, etc.

This work can be further extended to real time replacement of automotive components, including leaf spring, car panel, helmet, etc. The mechanical characteristics of the composites can be analysed under different working conditions to suggest for better design and green environment.

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